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AN INTENSIVE MONITORING STUDY OF TWO WETLANDS OF THE RIVER MURRAY IN SOUTH AUSTRALIA; PHYSICO-CHEMICAL PARAMETERS AND CYANOBACTERIA CONCENTRATIONS.

by A. M. OLSEN*

Summary

OLSEN, A. M. (1997) An intensive monitoring study of two wetlands of the River Murray in South Australia: physico-chemical parameters and cyanobacteria concentrations. *Trans. R. Soc. S. Aust.* **121**(4), 147-155, 28 November, 1997.

Quantitive data were collected on physico-chemical characteristics of surface water temperatures, pH, turbidity, conductivity, dissolved ammonia, dissolved reactive nitrate and total phosphate of Banrock and Loch Luna wetlands from 46 samplings in each wetland over a 20-month intensive monitoring study. Concentrations of the various physico-chemical parameters were within the ranges found in similar freshwater River Murray wetlands.

Weather factors, such as strong winds, heavy rain runoff and lightning, produced pertubations in turbidity, conductivity, dissolved reactive nitrate and total phosphate levels in the two wetlands.

Nutrient concentrations in excess of 0.36 mgl^{-1} total phosphate and 4.0 mgl^{-1} dissolved reactive nitrate with rising water temperatures were related to rapid cell multiplication of the cyanobacteria *Anabaena* spp. Three *Anabaena* spp. were predominant in the two wetlands and reached their greatest numbers (23,700 cells ml^{-1}) in Loch Luna from late December 1994 to mid - January 1995.

KEY WORDS: Wetlands, River Murray, monitoring physico-chemical parameters, cyanobacteria, South Australia.

Introduction

In 1990 the Murray Darling Basin Commission through its Natural Resources Management Strategy (NRMS) funded a preliminary study of the water chemistry and aquatic invertebrates and land vertebrates of 10 wetlands of the River Murray floodplains in South Australia (Goonan *et al.* 1992). The survey was conducted during May - June 1990. Between May 1990 and February 1992, a second more detailed physico-chemical and biological survey of eight alkaline freshwater wetlands was carried out on the above - mentioned floodplains. Five of the eight wetlands were located between Clover Lake (Calperum area) and the Berri Evaporation Basin and the remaining three were between Ramco Lagoon (Waikerie) and Lake Carlet (6 km upstream of Mannum) (Fig. 1). These results were reported by Suter *et al.* (1993).

Banrock Station floodplain (Section 662, 681 and 682 - Hundred of Moorook) and associated wetland lie in about the middle of the 100 km (approx.) stretch of the river between the five upper and three lower wetlands studied by Suter *et al.* (1993).

Flow regulation of the River Murray at Lock 3 in 1925 helped create two permanent freshwater wetlands in the region, one located in the floodplain of Banrock Station (34° 08′ S, 140° 20′ E) and the other in the Loch Luna Wetland Complex (34° 12′ S, 140° 22′ E) opposite Banrock Station and about one km upstream of Lock 3 weir (ANCA 1996). Banrock Station wetland has a 90 to 130 ha area depending on water depth (20 cm - 1.1 m) and was created in the 1950s by damming the upper section of Banrock Creek. The wetland behind the dam wall is gravity

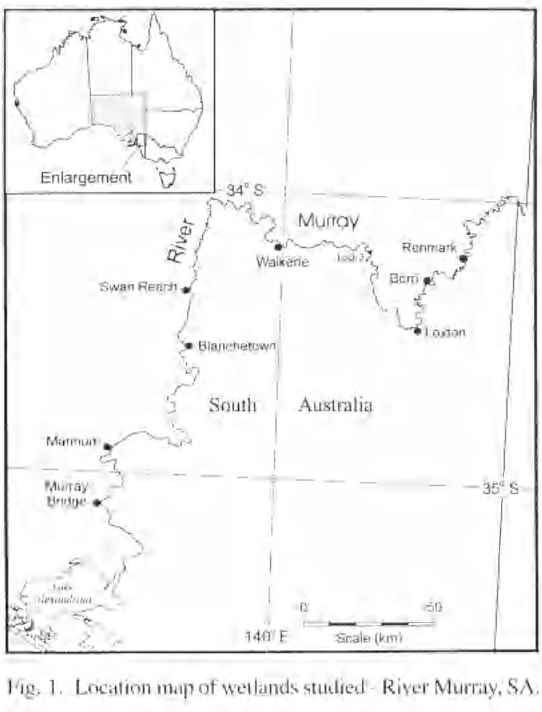

Fig. 1. Location map of wetlands studied - River Murray, SA.

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fed by a channel from Lock 3 Pool. Water levels are maintained by controls at the inlet and outlet points and discharges flow into Lock 2 Pool. European carp control structures were erected at the inlet in 1994.

The study described below was undertaken to determine the cyclical changes in the physico-chemical characteristics of the waters of the two wetlands and their influence on the rise and decline of those cyanobacterial species likely to produce toxic outbreaks. In the summer of 1991-2 there had been visible blue green algal blooms in both wetlands.

Materials and Methods

Sampling

This monitoring study of the two wetlands of the River Murray began in November 1994 and ended in June 1996. For 19 months water from only the River Murray catchment and upstream storages flowed through Lock 3 Pool. The Darling River did not flow because of the four-year drought in its drainage basin. Mixed River Murray - Darling River water flowed into Lock 3 Pool in June 1996 as a result of floods in the Darling River.

In each wetland, five sites were selected for water sampling for reasons of accessibility and representativeness and for sampling any increase in cyanobacterial concentrations irrespective of wind direction (Fig. 2). All water samples and temperature readings were taken in the morning and as near as possible to the same time at each visit. Wherever possible, Loch Luna was sampled first followed by Banrock wetland within 2 h. Collections of water samples were made weekly from October to December, fortnightly from January to March and monthly from

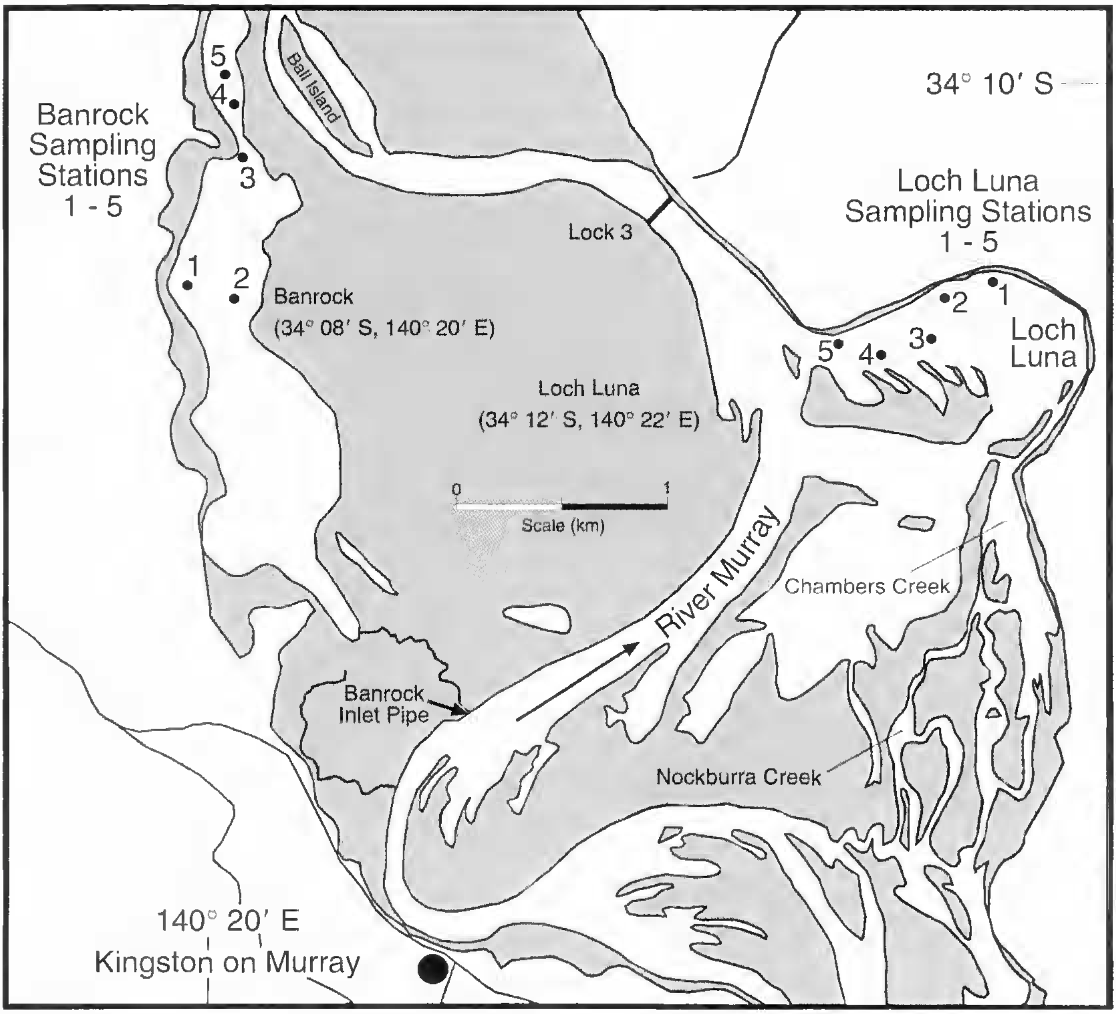

Fig. 2. Banrock and Loch Luna wetlands showing sampling sites. Note direction of flow.

TABLE 1. *Numbers of cells of* Anabaena *spp. and concentrations of dissolved reactive nitrate and total phosphate - Loch Luna 1994-96.*

Date	Cells (mgl^{-1})	DRNitrate (mgl^{-1})	Total phosphate (mgl^{-1})
Nov 3, 1994	+	0	0.16
Nov 8	0	0	0.13
Nov 15	0	0	0.17
Nov 22	56	0.44	0.20
Nov 29	41	Tr.	0.25
Dec 6	434	0.44	0.13
Dec 13	1,230	0	0.27
Dec 20	5,590	0.44	0.47
Dec 27	23,700	2.20	0.16
Jan 3, 1995	10,600	Tr.	0.46
Jan 17	14,500	6.1	0.19
Jan 31	1,050	0.44	0.45
Feb 14	3,560	Tr.	0.07
Feb 28	97	3.52	0.10
Mar 14	437	0.88	0
Mar 28	172	2.20	0.23
Apr 18	425	2.20	0.36
May 16	909	0	0.25
June 13	100	1.32	0.17
July 18	11	0	0.17
Aug 16	8	3.52	0.19
Sept 5	0	0	0.30
Sept 19	2	Tr.	0.07
Oct 3	0	Tr.	0.53
Oct 10	8	0	0.47
Oct 17	6	0	0.43
Oct 24	12	0	0.95
Oct 31	11	0.44	0.04
Nov 7	24	0	0.20
Nov 14	6	4.4	0.21
Nov 21	450	0	0.17
Nov 28	1,183	0	0.23
Dec 5	1,220	7.48	0.30
Dec 12	1,150	Tr.	0.40
Dec 19	115	Tr.	0.67
Dec 26	1,270	2.2	0.20
Jan 9, 1996	997	6.6	0.20
Jan 23	3,190	4.4	0.17
Feb 6	2,530	0	0.08
Feb 20	368	Tr.	0.25
Mar 5	63	contaminated	contaminated
Mar 19	444	0	0.23
Apr 14	57	0	0.12
May 14	0	0	0.41
Jun 9	0	0	0.06

TABLE 2. *Numbers of cells of* Anabaena *spp. and concentrations of dissolved reactive nitrate and total phosphate - Banrock 1994-1996.*

Date	Cells (mgl^{-1})	DRNitrate (mgl^{-1})	Total phosphate (mgl^{-1})
Nov 3, 1994	14	0	0.20
Nov 8	0	0.44	0.17
Nov 15	+	0.44	0.27
Nov 22	0	0	0.30
Nov 29	1,460	Tr.	0.27
Dec 6	2,480	3.5	0.41
Dec 13	1,560	Tr.	0.60
Dec 20	303	Tr.	0.70
Dec 27	125	0	0.23
Jan 3, 1995	96	Tr.	0.15
Jan 17	245	4.0	0.33
Jan 31	146	2.2	0.21
Feb 14	373	0	0.12
Feb 28	311	7.9	0.06
Mar 14	883	0.88	Tr.
Mar 28	5	0	0.33
Apr 18	123	0	0.27
May 16	189	Tr.	0.33
June 13		wetland drained	
July 18	50	0	0.20
Aug 16	0	0	0.24
Sept 5	+	0	0.40
Sept 19	+	Tr.	0.25
Oct 3	0	0	0.28
Oct 10	0	0	0.39
Oct 17	14	0	0.35
Oct 24	0	0	0.23
Oct 31	11	4.4	0.27
Nov 7	24	Tr.	0.26
Nov 14	27	0	0.30
Nov 21	225	0	0.16
Nov 28	626	3.52	0.30
Dec 5	461	Tr.	0.30
Dec 12	455	0	0.36
Dec 19	135	Tr.	0.43
Dec 26	364	Tr.	0.18
Jan 9, 1996	2,300	4.4	0.21
Jan 23	1,040	1.32	0.18
Feb 6	2,170	0	0.02
Feb 20	240	0	0.41
Mar 5	71	0	0.60
Mar 19	328	0	0.40
Apr 14	28	0	0.12
May 14	0	0	0.33
Jun 9	0	0	0.24

April to September on the dates given in Tables 1 and 2.

At each site (Fig. 2) a one-litre surface water sample was taken and bulked in a five litre plastic bottle with samples taken from the other four sites. Aliquots of the bulked sample were transferred to air-free 500 ml polycarbonate plastic screwtop bottles for subsequent physico-chemical analyses at the Science Section, Glossop High School. The one-litre water samples for counting cyanobacteria were transferred to 1.25 l plastic screwtop bottles leaving a 250 ml headspace. The samples were kept chilled until delivery to the Australian Centre for Water Quality Research, Bolivar SA for enumeration of cyanobacteria cells (HMSO 1990). The special 1.25 l plastic bottles for the water samples were supplied from the Water Quality Laboratory.

A floating "Der Grune Punkt" No. 7428, blue alcohol column thermometer was used to record the surface water temperatures at each site. A mean surface water temperature was then calculated for each wetland. A plastic bodied minimum - maximum thermometer, (-30° - +50° C) with pressure adjustment for indicators on the mercury column was used to record minimum and maximum water temperatures between times of consecutive sampling visits. It was suspended 15 cm below the surface.

There was no 13 June 1995 collection in the Banrock wetland because this wetland was drained for maintenance work on the irrigation pumps used for highland vineyard irrigation. The Loch Luna 5 March 1996 sample was discarded because of suspected contamination.

Chemical analyses

Water samples were held at 4° C until required and in most instances were analysed within 48 h. Measurements of turbidity, dissolved ammonia, dissolved reactive nitrate and total phosphate were made using a HACH DREL/5 instrument and premixed reagents (Hach 1984). For dissolved ammonia each sample was filtered through a Double Rings 201 filter paper to remove suspended solids. A 25 ml aliquot was measured into a clean glass sample cell and 1 ml of Nessler reagent added (Hach 1992). The mixture was left for colour to develop. In this case the blank was distilled water (25 ml) with 1 ml of Nessler reagent included. Measurements were made at 425 nm and recorded as mgl^{-1} after applying a conversion factor of multiplication by 1.29 (Hach 1992).

For dissolved reactive nitrate (DRN) each sample was filtered through a Double Rings 201 paper to remove clay particles. A 25 ml aliquot was measured into a clean glass sample cell and the contents of one foil sachet of premixed Nitraver 5 reagent[1] added. This mixture was rapidly agitated for one minute then left for five minutes for colour to develop. Another filtered 25 ml sample was used as a blank. Measurements were made at 500 nm and recorded as mgl^{-1} after applying a conversion factor of multiplication by 4.4 (Hach 1992).

For total phosphate (TP) a digestive process was used to convert all forms of phosphate to the soluble orthophosphate form (Hach 1992). Fifty ml of the sample were measured into a clean 125 ml Erlenmeyer flask along with 4 ml 5.25 N H_2SO_4 and two foil sachets of $K_2S_2O_8$ (Hach 1992). The mixture was heated in a boiling water bath for 30 minutes, allowed to cool to room temperature and then 4 ml 5 N NaOH were added. The sample was split into two 25 ml portions in clean glass sample cells. One foil sachet of premixed Phosver 3 reagent[1] was added to one container and the colour allowed to develop. The other was used as a blank for spectrometric analysis. Measurements were taken at 700 nm and recorded as mgl^{-1} after applying a conversion factor (division by 3). These DRN and TP results complement data collected for eight SA wetlands by Suter *et al.* (1993).

pH was measured using a Hanna HI 8424C pH meter. The probe was rinsed in distilled water between each test and left in the sample until the highest stable reading was reached.

For turbidity measurements, each sample was agitated vigorously and a 25 ml aliquot was added to a clean glass sample cell and placed in the DREL/5 spectrophotometer. Measurements were made at 450 nm and recorded as Nephelometric Turbidity (NT) units. A blank of distilled water was used to zero the instrument.

Conductivity measurements were made using a EDT FE 200 conductivity meter calibrated to 1413 Electrical Conductivity (EC) units between each use. The calibration solution was prepared by diluting 74.55 g of oven - dried KCl in 1000 ml distilled water. The probe was rinsed with distilled water prior to each use and the maximum reading taken each time it was used. Results were in EC units.

Results

Mean surface water temperatures

Throughout this study the mean surface water temperatures in the two wetlands showed almost identical trends. In general, water temperatures were higher in the more exposed shallow Banrock wetland than in the slightly more protected Loch Luna wetland. The highest surface water temperatures in Banrock, 28.5°, 28.6° and 28.4° C were recorded in the summer of 1994-5, corresponding temperatures

[1] Hach Co. Colorado USA

in Loch Luna were 27.4°, 28.5° and 25.3° C (Fig. 3). The lowest mean surface water temperatures were 10.3° C in Banrock and 10.2° C in Loch Luna on 18 July 1995.

In Banrock the greatest range in minimum and maximum water temperatures between consecutive visits was 20° C (15° - 35° C) between 3 and 17 January 1995 and the greatest range in Loch Luna was 14.5° C (14° - 28.5° C) between 22 and 29 November 1994. The monthly ranges in summer/autumn were often 15° C or greater, whereas in winter, they were 5° C or less. The least difference between minimum and maximum water temperatures between consecutive visits in Loch Luna was 0.5° C on 18 July 1995.

Lock 3 Pool surface water temperature 50 m upstream of the Banrock Station Intake in 1996 was slightly higher than the mean temperatures in Banrock and Loch Luna (Fig. 3).

pH

The pH values ranged up to 9.56 at Banrock (27 December 1994) and 9.04 at Loch Luna (3 January 1995) (Fig. 4). Lock 3 Pool water registered a maximum pH 8.62 on 14 November 1995 and a minimum pH 7.51 on 26 December 1995.

Turbidity

The shallower Banrock wetland mostly recorded higher turbidity values than those of Loch Luna (Fig. 5). Highest turbidity in Banrock was 200 NT units on 3 and 10 October 1995 and the lowest 30 NT units on 14 March and 28 November 1995 while in Loch Luna the highest turbidity was 170 NT units on 5 September 1995 and the lowest 10 NT units on 14 March 1995. Turbidity in Lock 3 Pool ranged 70 NT units on 14 May 1996 to 20 NT units on 26 December 1995. The mixed River Murray - Darling water had a turbidity value of 48 NT units on 9 June 1996.

Conductivity

The initial high conductivity of 1898 EC units in Banrock on 3 November 1994 decreased to 871 EC units in 6 weeks and more slowly thereafter to 500 EC units by 9 June (Fig. 6). In Loch Luna the initial conductivity of 1095 EC units on 3 November 1994 decreased to 687 EC units on 17 January 1995, rose slightly before falling to a minimum value of 327 EC units on 19 September 1995. Within a fortnight there were two sharp increases in concentrations (2720 EC units on 3 October 1995 and 1759 EC units on 31 October) before conductivity values decreased to 511 EC units on 9 June 1996.

The conductivity values of the River Murray water decreased slowly from 686 EC units on 31 October 1995 to 511 EC units on 14 May 1996. The mixed

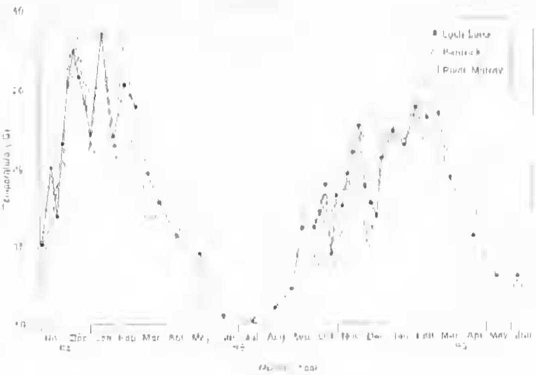

Fig. 3. Comparison of mean surface water temperatures at Banrock and Loch Luna, November 1994-June 1996 and River Murray, October 1995-June 1996.

Fig. 4. pH, Banrock and Loch Luna, November 1994-June 1996 and River Murray, October 1995-June 1996.

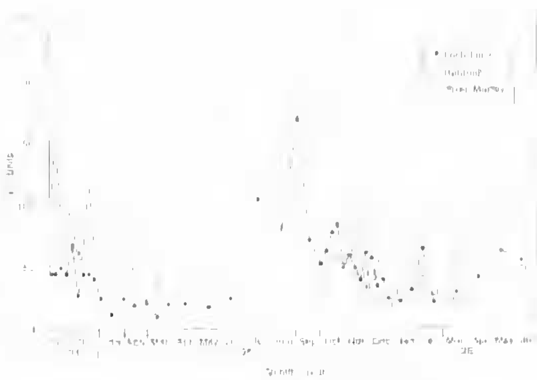

Fig. 5. Turbidity, Banrock and Loch Luna, November 1994-June 1996 and River Murray, October 1995-June 1996.

River Murray - Darling water was 438 EC units on 9 June 1996.

Rainfall

Weather factors, such as heavy rain and strong winds, were found to influence some physical parameters in the two wetlands. The average annual rainfall at Barmera is 245 mm. The Barmera rainfall was considered to be representative of the area and its daily rainfall records for the 20-month period of the study showed that rainfall was irregular with intermittent occasional heavy falls of 27 mm on 4 January 1995, 29 mm on 1 May, 53 mm on 23 October 1995, 38.5 mm on 2 January 1996, 25 mm on 27-28 February and 20.1 mm on 3-4 June 1996.

Dissolved ammonia

The patterns of dissolved ammonia (Fig. 7) were similar in both wetlands. The range in Banrock was from 0.17 mgl^{-1} on 28 November 1995 to 3.10 mgl^{-1} on 7 October 1995 and in Loch Luna from 0.30 mgl^{-1} on 3 January, 28 February and 31 October 1995 to 3.48 mgl^{-1} on 21 November 1995.

Dissolved Reactive Nitrate (DRN)

In Banrock there were occasional high DRN concentrations, exceeding 4 mgl^{-1}, in the period November to March 1994-5 and again on 31 October 1995 and 9 January 1996. At most other times DRN was below detection. In Loch Luna there was high DRN on 17 January 1995 and between October and February 1995-6 there were four occasions when the concentrations exceeded 4.0 mgl^{-1} (Fig. 8).

Total Phosphate (TP)

The highest TP concentrations recorded for Loch Luna were 0.95 mgl^{-1} on 24 October 1995 and 0.67 mgl^{-1} on 19 December 1995 (Fig. 9). At Banrock TP peaked at 0.7 mgl^{-1} on 20 December 1994. On 13 December 1994 and on 5 March 1996 the next highest Banrock values were 0.6 mgl^{-1}. The mean TP for both wetlands was similar at about 0.3 mgl^{-1}.

Cyanobacteria

When water sampling started in Banrock on 3 November 1994 the total cyanobacterial count was 14 cell ml^{-1} (Fig. 10). By 6 December 1994 cyanobacterial cells peaked in Banrock at 2480 cells ml^{-1} and then declined steadily to 5 cells ml^{-1} by 28 March. The second but smaller cyanobacterial cell multiplication in Banrock occurred a year later between 7 November 1995 and 9 January 1996. Cell numbers rose from 24 cells ml^{-1} to a maximum of 2300 cells ml^{-1} before declining to 71 cells ml^{-1} on 5 March 1996 (Table 2). Three *Anabaena* species were predominant in the Banrock wetland.

In Loch Luna between 1994 and 1995 the same

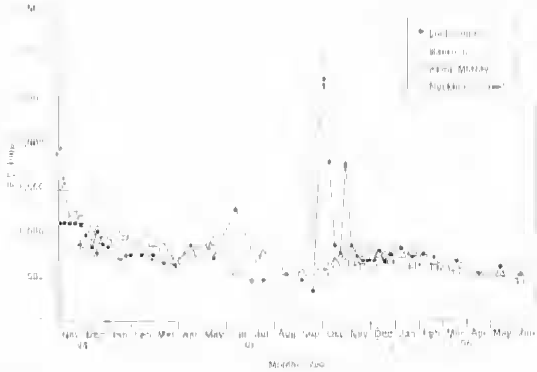

Fig. 6. Conductivity. Banrock and Loch Luna, November 1994-June 1996 and River Murray, October 1995-June 1996.

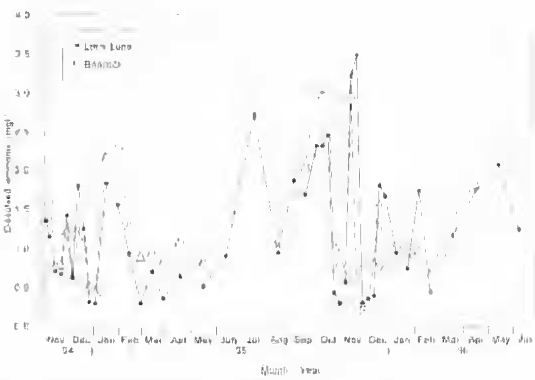

Fig. 7. Dissolved ammonia. Banrock and Loch Luna, November 1994-June 1996.

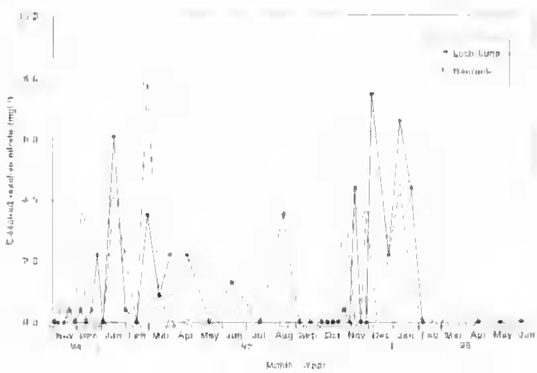

Fig. 8. Dissolved reactive nitrate, Banrock and Loch Luna, November 1994-June 1996.

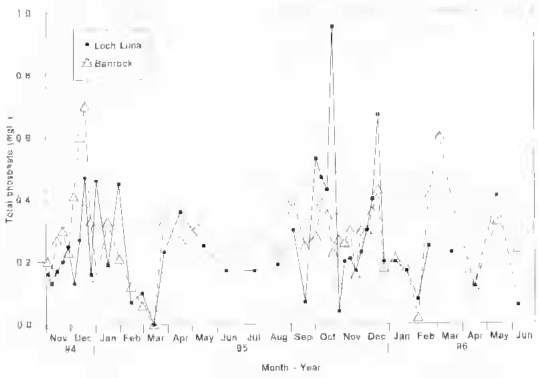

Fig. 9. Total phosphate, Banrock and Loch Luna, November 1994-June 1996.

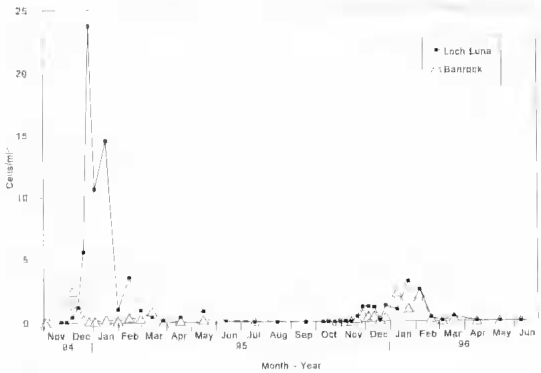

Fig. 10. Cyanobacteria (blue green algae), Banrock and Loch Luna, November 1994-June 1996.

three *Anabaena* species were predominant through the rise and subsequent decline of high cell multiplication (incipient blue green algal "bloom"). During November 1994 the number of cyanobacterial cells reached a low of 41 cells ml^{-1} but after 29 November their numbers increased rapidly to peak at 23,700 cells ml^{-1} on 27 December 1994 before declining to 97 cells ml^{-1} two months later (Fig. 10, Table 1). *Anabaena* coiled species was predominant until 3 January 1995 after which *Anabaena circinalis* displaced it until mid - February. The coiled species again became predominant until June 1995 when all three *Anabaena* species were present in low numbers until late November 1995 when multiplication of *Anabaena* coiled species began again. This species peaked at 2530 cells ml^{-1} in early February and a month later cell numbers fell to 63 cells ml^{-1} (Table 1). Cell numbers rose slightly to 444 cells ml^{-1} on 19 March 1996 but no cells were detected on 9 June 1996.

Other cyanobacterial species identified in the water samples, although occurring only in low numbers, were *Anabaenopsis elenkini* (6 December 1994 - 20 February 1995), *Aphanizomenon* sp. (22 November 1994 - 13 June 1995, 23 January - 19 March 1996), *Oscillatoria* sp. (3 November 1994 - 18 July 1995, 9 January - 19 March 1996). *Cylindrospermopsis raciborski, Planktothrix* spp., *Arthrospira* spp., *Microcystis aeruginosa* and *Pseudoanabaena* spp. were identified from time to time.

Discussion

Surface water temperatures, pH, turbidity and conductivity levels followed similar trends in both Banrock and Loch Luna wetlands and were comparable with the values recorded between 1990 - 1993 for the eight floodplain wetlands of the River Murray in South Australia by Suter *et al.* (1993).

River Murray turbidity values were highest (70 NT units) on 14 May 1996 and lowest (20 NT units) on 26 December 1995. Mixed waters of River Murray and Darling River (Lock 3 Pool) registered 48 NT units on 9 June 1996. In the 10-year period 1978-88 Lock 3 Pool water averaged 60 NT units (Mackay & Eastburn 1990).

The high conductivity value of 1898 EC units in Banrock on 3 November 1994 was caused by a blocked inlet pipe into Banrock; with the clearing of the blockage conductivity values in one week dropped to 1507 EC units. Turbidity in Banrock increased from 104 to 155 NT units between 5 and 8 November 1994 due to turbulence from the rush of water following clearing of the blockage. Seven weeks for conductivity values and five weeks for turbidity values were required to reach equivalence with Loch Luna values.

In Loch Luna conductivity levels rose from 327 to 2720 EC units on 3 October 1995 after spring rains and strong runoff. At Barmera, 13 mm of rain fell on 31 August, 9.6 mm on 5 September, 9.8 mm on 25 September, 10 mm on 3 October and 53 mm on 23 October 1995. Seiche effects in Lake Bonney and added runoffs caused the high conductivity water from Lake Bonney to flow through Chambers Creek into Loch Luna wetland. The outward movement of the high conductivity water (2970 EC units) from Lake Bonney was traced from data recorded on 6 October 1995 at position PO1517 in Nockburra Creek, a tributary of Chambers Creek. Six weeks elapsed before the high conductivity water from Lake Bonney had been diluted to 721 EC units (14 November 1995).

The range of DRN concentrations in Banrock was 0 - 7.9 mgl^{-1} and in Loch Luna 0 - 7.48 mgl^{-1}. The high registrations occurred mainly after heavy rains but there are also nitrate contributions from time to time from water from the River Murray and from agricultural drains, town effluents and sewage discharges as well as localised autolytic breakdown of nitrogen - fixing blue green algae (*Anabaena* spp.). There is an unknown DRN nutrient input from huge flocks of pelicans (> 1000 birds), swans, cormorants and ducks and lesser numbers of other water birds resident in Banrock and Loch Luna wetlands and on the banks of the River Murray. Nitrates are also produced by lightning (Smith 1996).

The highest TP level (0.95 mgl^{-1}) recorded in Loch Luna occurred on 24 October 1995 the day after 53 mm of rain fell at Barmera and 58 mm at Banrock Station (C. L. Rohrlach pers. comm. 1995). Such heavy rain and consequent runoff cause bottom disturbances in shallow wetlands which redistribute dissolved organic phosphorus compounds and inorganic phosphorus bound to suspended or disturbed bottom organic particulates in the water column. Briggs *et al.* (1985) have also drawn attention to the complexity of chemical relationships within wetlands and the effects of weather factors, such as winds and temperature, on water chemistry.

No blooms of cyanobacteria were observed in Banrock wetland. The multiplication of cyanobacterial cells in Banrock during December 1994 was halted by the increased water inflow following removal of the blockage in the inlet pipe. The cyanobacteria were flushed out preventing any further development of a cyanobacterial bloom in Banrock wetland that year.

In Loch Luna cyanobacterial cells reached a maximum of 23,700 cells ml^{-1} on 27 December before declining to zero by 14 March 1995. After the collapse of the cyanobacterial population in Loch Luna in December 1994, a small but visible blue green algal bloom developed downstream in February and March 1995 along the eastern bank of the River Murray adjacent to Lock 3 weir. It is likely that this bloom had its genesis in the November - December 1994 cell multiplication in Loch Luna upstream and on the same side of the River Murray. Small blue green algal blooms had occurred in this same location in previous years (Lock 3 staff pers. comm. 1995).

Bowling (1994) reported the occurrence and possible causes of a severe *Anabaena circinalis* bloom in Lake Cargelligo NSW in late 1990-91 when cell numbers exceeded 100,000 cells ml^{-1}. The physico-chemical levels in the lake in 1990 had ranges close to the 1994-6 values in Loch Luna for water temperatures, pH, turbidity and conductivity but lower maxima in concentrations of TP and DRN than were found for Loch Luna. Bowling (1994) expressed the view about the Lake Cargelligo bloom that "although several underlying causes of this bloom are probable, the elevated nutrient concentrations, especially of total phosphorus, were major factors that contributed to it." He drew attention to the fact that most physico-chemical studies of cyanobacteria blooms were started after the blooms had occurred.

In this study of the physico-chemical properties of the two wetlands a search for bloom - forming toxic cyanobacteria species was started before any cell multiplication had commenced and a seasonal pattern is described. Cyanobacterial cells may remain dormant in cold waters and grow best at water temperatures exceeding 15° C, with optimal growth rates at 25° C or higher (Robarts & Zohary 1985). The effect of water temperatures on cyanobacterial cell numbers in Loch Luna is shown with data from Table 1 which show that blooms only occurred between November and February. Numbers of *Anabaena* spp. rose suddenly from zero on 15 November 1994 (20.1° C) to 23,700 ml-1 on 27 December 1994 (24.2° C) and then began subsiding, even though the water temperatures were high, perhaps because of exhaustion of nutrients.

The rise and fall in cell numbers may also be related to the concentrations of the two nutrients, DRN and TP recorded during the growth and decline of the 1994-5 and 1995-6 blue green algal outbreaks (Table 1). However, since the concentration of dissolved reactive phosphorus is not known, these relationships must be treated with caution.

There were four occasions (20 December 1994, 3 and 31 January 1995 and 18 April 1995) when TP concentrations in Loch Luna were at or above 0.36 mgl^{-1} and DRN was present even in low concentrations (Tr. - 2.2 mgl^{-1}). After each of these events there was a rise in the numbers of cyanobacterial cells. In October 1995 (mean 16.9° C) there were four TP concentrations between 0.43 and 0.95 mgl^{-1} but DRN was low or absent and no cell multiplication developed.

A pattern related to nutrient availability and temperature can be seen in early 1996. After an increase to 3190 cells on 23 January 1996 the cell numbers began to decline possibly due to very low concentrations of DRN and fluctuating values of TP in the water column. The cyanobacteria population reached zero on 14 May 1996. The mean water temperature on that date was 13° C which is near the minimum temperature range for growth of many free living cyanobacteria species.

From the data obtained in this study it is suggested that outbreaks of cyanobacterial blooms did not occur in the summers of 1994-5 and 1995-6 because there were inadequate concentrations of TP and DRN in the water column during the period of favourable growth for cyanobacteria. Data from this study indicate that TP concentration above 0.36 mgl^{-1}

and DRN concentration at or above 4.0 mgl^{-1} in the wetland may provide for continuous growth in the *Anabaena* species.

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